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FINANCIAL DEVELOPMENT, INCOME INEQUALITY AND CARBON EMISSIONS IN SUB-SAHARAN AFRICAN COUNTRIES: A PANEL DATA ANALYSIS

Nicholas M. Odhiambo

Abstract

This paper examines the dynamic relationship between financial development, income inequality and CO₂ emissions in a step-wise fashion, using data from 39 sub-Saharan African (SSA) countries during the period 2004-2014. The study uses three income inequality indicators: the Gini coefficient, the Atkinson index and the Palma ratio, to examine these linkages. The study employs the generalised method of moments (GMM) as the estimation technique. The empirical findings show that financial development unconditionally reduces CO₂ emissions (metric tons per capita) in SSA countries. The findings also show that there are threshold levels of income inequality that should not be exceeded in order for the negative impact of financial development on CO₂ emissions to be sustained. Specifically, the study finds that the negative impact of financial development on CO₂ emissions is likely to change to positive if the following inequality levels are exceeded: 0.591, 0.663 and 5.454 respectively for the Gini coefficient, the Atkinson index and the Palma ratio. The findings of this study have far-reaching policy implications, not only for SSA countries, but also for developing countries as a whole. Policy implications are discussed.

JEL Classifications: Q43, C32

Keywords: Sub-Saharan Africa; Financial Development; CO₂ Emissions; Income Inequality, GMM

Introduction

The relationship between financial development and carbon dioxide (CO₂) emissions has attracted a conglomerate of literature in recent years. There are two contrasting views regarding the relationship between financial development and CO₂ emissions. The first argues that financial development may contribute significantly to a reduction in CO₂ emissions. Studies that support this view argue that financial development could lead to a reduction in CO₂ emissions through growth and foreign direct investment (FDI) channels (Acheampong, 2019; Tamazian *et al*, 2009). In this view, financial development could attract FDI and higher R&D investment, thereby leading to an increase in economic growth and a decrease in environmental degradation (see also Gok, 2020). A developed financial system may attract foreign investors

who may invest in clean energy or research and development (RD) projects. Through foreign direct investment, financial development could lead to the transfer of green technologies from home countries to host countries (Acheampong 2019). This would lead to environmentally friendly technology that eventually reduces carbon emissions. In addition, foreign capital inflow could assist host countries – and in particular emerging economies – to finance clean energy projects (Paramati *et al*, 2017). Moreover, increased access to new technology could enable firms to adopt more energy-efficient and environmentally friendly production processes, which could eventually lead to a decrease in environment degradation (Acheampong 2019; Abbasi & Riaz 2016). By providing access to low-cost capital, financial development also creates incentives for firms and governments to invest in environment-friendly technology, which further reduces CO₂ emissions (Dasgupta *et al*, 2001; Tamazian *et al*, 2009; Tamazian & Rao, 2010; Yuxiang & Chen, 2010). A developed financial market also allocates the available funds efficiently, thereby enabling domestic businesses to purchase environmentally friendly technology (Frankel & Rose, 2002). Previous studies have also shown that financial development could also promote good corporate governance and makes firms more sensitive to environmental degradation (Claessens & Feijen 2007). Other studies have also shown that stock markets are more likely to punish businesses that perform poorly in environmental terms (Salinger, 1992) and reward businesses that perform well in terms of environmental friendliness (Klassen & McLaughlin, 1996).

Unlike the first view, the second argues that a developed financial system could exacerbate rather than mitigate CO₂ emissions. Studies supporting this view argue that financial development could fuel environmental degradation through energy consumption and industrialisation channels (Abbasi & Riaz, 2016; Acheampong, 2019). Some of these studies argue that, through financial development, households are able to access credit easily, which enables them to buy high-energy-demanding home appliances and motorcars, thereby leading to an increase in energy consumption and an increase in CO₂ emissions (Xing *et al*, 2017; Acheampong, 2019; Sadorsky, 2010). Also, financial development enables firms to purchase more machinery and equipment due to easy access to credit, thereby leading to a further increase in CO₂ emissions. Access to easy credit also allows firms to invest in new plants, which ultimately leads to an increase in energy consumption (Acheampong, 2019; Sadorsky, 2010). This leads to more carbon emissions and environmental degradation. Financial development is also likely to boost industrialisation, which may eventually lead to an increase in greenhouse

gas emission (Acheampong, 2019)¹. By providing financial assistance to domestic business, financial development leads to an increase in the number and size of manufacturing firms, which could eventually lead to an increase in land degradation, pollution and carbon emissions (see Aye & Edoja, 2017). Some previous studies have also argued that banks may be less suited to reduce environmental pollution when compared with other institutions. This is because banks have been found to be technologically conservative and may be reluctant to fund newer and possibly cleaner technologies that could erode the value of the collateral that underlies existing loans that mostly represent older and possibly dirtier technologies (Minetti, 2011). Some studies have also argued that banks are hesitant to finance green technologies if they are related to innovations that involve assets that are intangible, business-specific and linked to human capital (Hall & Lerner, 2010). This is because such intangible assets are difficult to redeploy elsewhere and consequently hard to collateralise (Carpenter & Petersen, 2002).

Although there is a clear theoretical link between financial development and CO₂ emissions, very few empirical studies have been conducted on the impact of financial development on carbon emissions in sub-Saharan African (SSA) countries. Most of the previous studies in developing countries have focused mainly in Asia and Latin America (see, for example, Omri *et al.*, 2015; Hao *et al.*, 2016; Cetin *et al.*, 2018; Lu, 2018; Bekhet *et al.*, 2017). Moreover, most of the previous studies on this subject have focused either on the causal linkage between financial development and CO₂ emissions, or on the relationship between CO₂ emissions and energy consumption. In addition, in most of the previous studies, the role of socio-economic indicators, like income inequality, in modulating the effect of financial development has not been fully explored. In particular, the threshold level of income inequality that determines the impact of financial development on CO₂ emissions has not been fully investigated by the previous studies. Even in countries where those studies were conducted, the effect of financial development on carbon emissions remains at best inconclusive (see, for example, Jalil & Feridun, 2011; Omri *et al.*, 2015; Al-Mulali *et al.*, 2015; Cetin *et al.*, 2018).

It is against this lacuna that the current study aims to examine the dynamic relationship between financial development, income inequality and CO₂ emissions in 39 SSA countries during the period 2004–2014. The study attempts to answer three critical questions: 1) Does financial development have any effect on CO₂ emissions? 2) Does the level of income inequality mitigate

¹ See Gok (2020).

the impact of financial development on CO₂ emissions? 3) Is there a threshold level of income inequality that influences the impact of financial development on CO₂ emissions in SSA countries? The study uses three indicators of income inequality: the Gini coefficient, the Atkinson index and the Palma ratio, while financial development is proxied by private domestic credit from deposit banks and other financial institutions.

To examine the effect of income inequality in mitigating the impact of financial development on CO₂ emissions in the selected SSA countries, the study uses interactive terms that interact the income inequality proxies (i.e. the Gini coefficient, the Atkinson index and the Palma ratio) with the financial development variable. To our knowledge, this may be the first study of its kind to examine in detail the link between financial development, income inequality and carbon emissions in sub-Saharan African countries using the GMM estimation technique.

The rest of the paper is organised as follows: In the next section, some previous empirical studies on the relationship between financial development and CO₂ emissions in both developing and developed countries are reviewed. This is followed by the methodology section. In the penultimate section, the empirical analysis and the discussion of the results are presented. In the final section, the conclusions and policy recommendations are presented.

Overview of empirical literature

The relationship between financial development and CO₂ emissions has received emphasis from a number of empirical studies in recent years, but with conflicting results. While some earlier studies have found a negative relationship between financial development and CO₂ emissions, some have found a distinct positive relationship between these two variables. In between these two extreme findings, there are studies that have failed to find any formidable relationship between financial development and CO₂ emissions.

Studies with findings that support a negative relationship between financial development and carbon emissions include studies like those of Tamazian *et al* (2009), Tamazian and Rao (2010), Jalil and Feridun (2011), Shahbaz *et al* (2013), Omri *et al* (2015), Dogan and Seker (2016), Saidi and Mbarek (2017), Xing *et al* (2017), Xiong and Qi (2018), Zaidi *et al* (2019), and Zafar *et al* (2019), among others. Tamazian *et al.* (2009), for example, while examining whether higher economic and financial development leads to environmental degradation in BRIC countries using panel data analysis, found that financial development lowers the quantity of

carbon emissions in the studied countries. Tamazian and Rao (2010), while examining the relationship between financial development and environmental degradation in 24 transition economies using the system Generalize Method of Moments (GMM) estimation technique, found that financial development plays a positive role in environmental disclosure in transitional economies and could therefore help to reduce carbon emissions. While examining the impact of growth, energy and financial development on the environment in China using the Autoregressive Distributed Lag (ARDL) bounds testing procedure, Jalil and Feridun (2011) found that financial development has led to a decrease in environmental pollution. Shahbaz et al. (2013), while examining the effects of financial development, economic growth, coal consumption and trade openness on CO₂ emissions in South Africa, found that financial development could reduce carbon emissions in South Africa. Omri et al. (2015) examined the relationship between financial development and carbon emissions in 12 Middle East and North Africa (MENA) countries. Using the simultaneous-equation panel data model, they found that higher levels of financial development could lower carbon emissions by promoting technological innovations and increasing the input in the energy conservation research and development. Dogan and Seker (2016) examined the long-run dynamic relationship between financial development and carbon emissions using a panel data of 23 top renewable energy countries during the period 1985–2011. Their findings showed that financial development could indeed reduce carbon emissions. Saidi and Mbarek (2017) also investigated the effect of financial development on carbon emissions in 19 emerging economies for the period 1990–2013. Using a system GMM model and the time-series techniques, they found that financial development had a long-term negative impact on carbon emissions. Xing et al. (2017), while examining the role of financial development in China's carbon emissions reduction process using the ARDL approach, also found that financial development could improve carbon emissions. Xiong and Qi (2018), while examining the relationship between financial development and carbon emissions in Chinese provinces using a spatial panel data analysis, found that financial development reduced carbon emissions per capita in the Chinese provinces. Zaidi et al. (2019), while examining the dynamic relationship between globalization, financial development and carbon emissions using a panel data of 17 Asia-Pacific Economic Cooperation (APEC) countries, found that financial development could reduce carbon emissions in both the short run and the long run. Likewise, Zafar et al. (2019), while examining the impact of globalisation and financial development on environmental quality in selected Organisation for Economic Co-operation and Development (OECD) countries, found that financial development could reduce carbon emissions in the studied countries.

Apart from the above-mentioned studies, there are studies with findings supporting a positive relationship between financial development and CO₂ emissions. These include studies by Zhang (2011), Al-Mulali et al. (2015), Shahbaz et al. (2016), Lu (2018), Cetin et al. (2018), and Ali et al. (2019), among others. Zhang (2011), for example, while examining the impact of financial development on carbon emissions in China, found that China's financial development acted as an important driver for the increase in carbon emissions. Al-Mulali et al. (2015), while examining the influence of economic growth, urbanisation, trade openness, financial development, and renewable energy on pollution in Europe, using the panel-pooled Fully Modified Least Squares (FMOLS) model, found that financial development could increase carbon emissions in the long run. Shahbaz et al. (2016), while examining the asymmetric impact of financial development on carbon emissions in Pakistan using quarterly data, found that financial development in the banking sector could increase carbon emissions via positive shocks, and this appears to be a unidirectional causality. Cetin et al. (2018), while examining the relationship between financial development and carbon emissions in Turkey using the ARDL bounds testing approach, found that there is a positive relationship between financial development and carbon emissions in the long-run. Ali et al. (2019), while examining the dynamic relationship between financial development and carbon emissions in Nigeria using the ARDL bound test approach, also found financial development to have a positive and significant impact on carbon emissions both in the long run and in the short run.

While the above-mentioned studies tend to support either a positive or a negative relationship between financial development and CO₂ emissions, there are a few studies that have found that the relationship between these two variables depends on the level of economic development. Other studies have also found the relationship between these two variables to be neutral. Hao et al. (2016), for example, while examining the relationship between financial development and environmental quality in 29 Chinese provinces using the GMM, found that the relationship between financial development and CO₂ emissions depends on the level of economic development. The authors found that at low levels of economic growth at the early stages of economic growth, financial development is environmentally friendly. However, as the economy becomes more developed, a higher level of financial development tends to be more harmful to the environment. However, Omri *et al.* (2015), while examining the causal relationship between financial development, environmental quality, trade and economic growth in the Middle East

and North African (MENA) countries, found that the relationship between financial development and carbon emissions in these countries supported the neutrality hypothesis.

Methodology

GMM specification

Although the traditional First-Difference (FD) GMM is good at eliminating the fixed effect as well as time-invariant regressors, it has been found to be biased and have poor finite sample properties when the series is highly persistent (Blundell and Bond, 1998). As explained by Blundell and Bond (1998), if the instruments used in the FD estimator are weak, then the differenced GMM results are expected to be biased in the direction of within groups (Blundell and Bond, 1998:10). In order to remedy this bias, a system GMM has been found to be superior because, by adding additional moment restrictions, the system GMM tends to restrict the lagged first differences that are used as instruments in the levels equations. This helps to correct any potential bias that would emerge using the standard GMM estimator (Arellano and Bover, 1995; Blundell and Bond, 1998). In other words, unlike the first-differences GMM that only uses moment conditions from the estimated first differences of the error term; the system GMM uses both the moment conditions from the first difference of the error term and the levels of the residuals.

The advantages of using the GMM compared with other panel data techniques have been documented in the literature (Asongu and Odhiambo, 2020a, 2019a). Firstly, the GMM approach enables a study to account for the potential sources of endogeneity between the explanatory variables by controlling: 1) the unobserved heterogeneity with time-invariant omitted variables; and 2) simultaneity in all regressors by employing instrumented explanatory variables (Boateng et al., 2018). While the reverse causality is controlled by the inclusion of internal instruments, the unobserved heterogeneity is controlled by accounting for time-invariant omitted variables in the estimation exercise (Asongu and Odhiambo, 2019b). Unlike cross-sectional data, which cannot control for time-invariant unobserved heterogeneity, panel data can be used to control for time-invariant unobserved heterogeneity. This means that cross-sectional data is more likely to suffer from omitted variable bias than panel data. Secondly, by using the GMM, the cross-country variations are controlled in the regressions. Thirdly, as reported by Bond et al. (2001), the GMM estimator corrects biases associated with the

difference estimator (Arellano and Bond, 1991)². The only condition that applies when the GMM is applied is that one has to keep an eye on the possible proliferation of instruments that could possibly overfit the endogenous variables. In other words, one has to make sure that the model passes both the test for instrument validity and the test for second-order serial correlation (Arellano and Bond, 1991).

In view of the aforementioned, the current study uses an extension of the difference GMM techniques by Roodman (2019a) to examine the relationship between financial development, income inequality and carbon emissions in 39 SSA countries during the period 2004 to 2014³. The choice of the underlying estimation approach is motivated by the fact that it has been documented to limit the proliferation of instruments and produce more robust estimates (Asongu and Odhiambo, 2020b, 2020c). The motivation for using the GMM in the current study is based on a number of justifications, which have been supported by previous studies, such as Asongu and Nwachukwu (2016), Tchamyou (2019a, 2019b), and Fosu and Abass (2019), among others. Firstly, the GMM allows for the control for persistence in the variables employed in this study. Secondly, as required by the GMM technique, the number of countries (cross-sections) should be significantly higher than the time periods (the number of years) for each cross-section (country). In this study, the number of cross-sections is 39 and the number of corresponding periods for each cross-section is 11; hence, $N (39) > T (11)$. This implies that the condition for employing the GMM approach is fulfilled. Following Tchamyou et al. (2019a, 2019b), the GMM estimation model used in this study can be expressed as follows:

Variables in levels

$$CO2_{i,t} = \sigma_0 + \sigma_1 CO2_{i,t-\tau} + \sigma_2 FD_{i,t} + \sigma_3 Ineq_{i,t} + \sigma_4 FDxIneq_{i,t} + \sum_{h=1}^2 \delta_j CV_{h,i,t-\tau} + \eta_i + \xi_t + \varepsilon_{i,t} \quad (1)$$

²See also Boateng et al (2018) and Asongu and Odhiambo (2018).

³The 39 sampled countries are: “Angola; Benin; Botswana; Burundi; Cabo Verde; Cameroon; Central African Republic; Chad; Comoros; Congo Democratic Republic; Congo Republic; Cote D’Ivoire; Eswatini; Gabon; Gambia; Ghana; Guinea; Guinea-Bissau; Kenya; Lesotho; Liberia; Madagascar; Malawi; Mali; Mauritius; Mozambique; Namibia; Niger; Nigeria; Rwanda; Sao Tome and Principe; Senegal; Seychelles; Sierra Leone; South Africa; Sudan; Tanzania, Togo and Uganda”

Variables in First Difference

$$\begin{aligned}
& CO2_{i,t} - CO2_{i,t-\tau} \\
& = \sigma_1(CO2_{i,t-\tau} - CO2_{i,t-2\tau}) + \sigma_2(FD_{i,t-\tau} - FD_{i,t-2\tau}) + \sigma_3(Ineq_{i,t} - Ineq_{i,t-\tau}) + \sigma_4(FDxIneq_{i,t} \\
& \quad - FDxIneq_{i,t-\tau}) + \sum_{h=1}^2 \delta_h(CV_{h,i,t-\tau} - CV_{h,i,t-2\tau}) \\
& \quad + (\xi_t - \xi_{t-\tau}) + (\varepsilon_{i,t} + \varepsilon_{i,t-\tau})
\end{aligned} \tag{2}$$

where, $CO2_{i,t}$ denotes carbon emissions per capita in metric tons of country i in period t , σ_0 is a constant. FD is a financial development indicator (i.e. private domestic credit by deposit banks and other financial institutions) of country i in period t . $Ineq$ denotes inequality measurement (i.e. the Gini coefficient, the Atkinson index and the Palma ratio) of country i in period t . $FDxIneq$ represents interactions between various indicators of inequality and the financial development measurement (i.e. $FDxGini$, $FDxAtkinson$ and $FDxPalma$). CV is a vector of control variables, i.e. mobile phone penetration and regulation quality. τ represents the coefficient of auto-regression, ξ_t is the time-specific constant, η_i is the country-specific effect and $\varepsilon_{i,t}$ the error term.

Identification and exclusion restrictions

Identification, simultaneity and exclusion restrictions are an integral component of the GMM specification. Following previous empirical studies, this study assumes that all explanatory variables are either predetermined or suspected to be predetermined, while time-invariant omitted variables are assumed to be exogenous (see Asongu and Nwachukwu, 2016; Dewan and Ramaprasad, 2014; Asongu and Odhiambo, 2019a). This is because it is not feasible for years or time-invariant omitted variables to become endogenous in difference (Roodman, 2009b). Consequently, the `gmmstyle` procedure is used for the predetermined or suspected endogenous variables, while ‘`ivstyle`’ – ‘`iv (years, eq (diff))`’ procedure is used for treating time-invariant omitted variables. In other words, only years are treated as strictly exogenous because it is highly unlikely for the years to become endogenous in first-difference (Roodman, 2009b).

In order to address the endogeneity problem, the study uses lagged regressors in the model as instruments for forward-differenced variables. In doing so, the fixed effects are removed and can no longer influence the investigated nexuses. Consistent with Arellano and Bover (1995)

and Love and Zicchino (2006), the study performs Helmert transformations in order to purge fixed effects that are likely to be associated with error terms and that could potentially bias the examined connections (see also Asongu and Nwachukwu, 2016; Asongu and De Moor, 2017). Helmert (forward-orthogonal) transformations in this case involve forward mean-differencing of the variables. The approach requires that the mean of future observations is subtracted from variables instead of the previous observations being subtracted from the current observations, which ensures parallel or orthogonal conditions between forward-differenced variables and lagged values (Roodman, 2009a; Asongu and De Moor, 2017). Regardless of the number of lags used, these transformations prevent data loss for all observations with the exception of the last for each cross-section. Moreover, since lagged observations do not enter the formula, they remain valid as instruments (see Roodman, 2009b:104; Asongu and Nwachukwu, 2016; Asongu and De Moor, 2017).

Regarding the exclusion restriction, the study treats years as strictly exogenous; hence, they are expected to influence the outcome variable exclusively via endogenous explaining variables (Asongu and Odhiambo, 2019a). For this purpose, the study uses the Difference in Hansen Test (DHT) for instrument exogeneity to test the validity of the exclusion restriction (Asongu and Nwachukwu, 2016). According to this test, for the instruments to explain the dependent variable exclusively via suspected endogenous variables, the alternative hypothesis of the test must be rejected (see Tchamyou and Asongu, 2017; Tchamyou, 2020).

Data

The outcome variable, which is CO₂ emissions (metric tons per capita), is obtained from World Development Indicators (WDI) of the World Bank and informed by recent CO₂ emissions literature (Asongu and Odhiambo, 2020a). The study is consistent with recent inequality literature in adopting three inequality measures in order to account for income inequality (Naceur and Zhang, 2016; Meniago and Asongu, 2018; Tchamyou et al., 2019a). These are the Gini coefficient, the Atkinson index and the Palma ratio. The last-two indicators are used to complement the Gini coefficient because they capture tails or extreme points (i.e. most poor and most rich) of the income distribution. According to the existing literature: (i) The Gini coefficient indicates wealth distribution across the population; (ii) the Atkinson index measures the percentage of total income that a particular society is willing to forego in order to have more income equality among citizens; and (iii) the Palma ratio reflects national income shares of the

top 10% of households to the bottom 40%. The data for inequality indicators are obtained from the Global Consumption and Income Project (GCIP).

Financial development variable is proxied by private domestic credit by deposit banks and other financial institutions. Hence, it is a measure of financial development that incorporates both the formal and the semi-formal financial sectors. The motivation for using this proxy is based on the fact that it is one of the best indicators of financial development that is linked to income inequality. The data for this variable is obtained from the Financial Development and Structure Database (FDSD) of the World Bank. In the conception and definition of the financial development indicator, “other financial institutions” denote financial institutions that are legally registered but not licensed by the central bank or government. These include, among others: microfinance, credit unions and non-governmental organizations (NGOs), which entail microenterprises and the entrepreneurial poor (Asongu and Acha-Anyi, 2017). This makes the adopted financial development indicator to be linked to the poor; and hence, associated with income inequality.

The data for the control variables, which include mobile phone penetration and regulation quality, are obtained from the WDI and World Governance Indicators (WGI) of the World Bank. The choice the mobile phone and regulation as control variables is consistent with recent CO₂ emissions literature (see Asongu, 2018a; Asongu and Odhiambo, 2020c). In this study, the coefficient of mobile phone penetration is expected to be positive and statistically significant, while the coefficient of the regulation quality is expected to have the opposite effect (see Asongu, 2018a). The choice of the two control variables is also consistent with recent GMM literature on the need to limit control variables in order to avoid instrument proliferation, even when the option of collapsing instruments is taken into account (Osabuohien and Efobi, 2013; Asongu and Nwachukwu, 2017). It is also worth noting that previous studies, such as Bruno, De Bonis and Silvestrini (2012) and Osabuohien and Efobi (2013) used no control variables, while Asongu and Nwachukwu (2017) and Asongu and Odhiambo (2020d) used two control variables. The definitions and sources of the variables are provided in Appendix 1, while the summary statistics and the correlation matrix are presented in Appendices 2 and 3, respectively.

Empirical analysis

The empirical results reported in Table 1 consist of three main sets of specifications, each corresponding to the respective inequality indicator, namely the Gini coefficient, the Atkinson

index and the Palma ratio. For each inequality indicator, two specifications are reported: one without a conditioning information set and another with a conditioning information set.

Four main information criteria are used in this study to assess the validity of the estimated GMM models: 1) the second-order Arellano and Bond autocorrelation test (AR (2)) in difference has been used to test for the absence of autocorrelation in the residuals; 2) the Sargan and Hansen over-identification restrictions (OIR) tests⁴; 3) the Difference in Hansen Test (DHT) for exogeneity of instruments, which has been employed to assess the validity of results from the Hansen OIR test; and 4) the Fisher test for the joint validity of the estimated coefficients. Based on these criteria, only one specification (i.e. the Palma ratio specification) without the control variables is not valid. This is because the null hypothesis of the Hansen test in this specification has been rejected. Based on the results reported in Table 1, it can be concluded that, on the whole, an increase in financial development leads to a decrease in CO₂ emissions in the studied countries. Although this finding is contrary to the results of some previous studies, *inter alia* those by Zhang (2011) for the case of China, Al-Mulali et al. (2015) for Europe, Shahbaz et al. (2016) for Pakistan, and Ali et al. (2019) for Nigeria, it is consistent with studies, like those by Tamazian et al. (2009) for BRIC countries, Omri et al. (2015) for 12 MENA countries, Saidi and Mbarek (2017) for 19 emerging economies and Zaidi et al. (2019) for 17 Asia-Pacific Economic Cooperation (APEC) countries, among others. The negative impact of financial development on CO₂ emissions has been supported by the negative coefficient of financial development in the CO₂ emissions equation in all the income inequality specifications, with the exception of the first specification of the Gini Coefficient. The results also show that income inequality consistently interacts with financial development to reduce CO₂ emissions in the sampled countries. This is supported by the corresponding interactive terms between: i) financial development and the Gini coefficient; ii) financial development and the Aktinson index; and iii) financial development and the Palma ratio in the CO₂ emissions equation. In addition, the study also found the control variables, namely mobile phones and regulation quality, to be statistically significant with the anticipated signs as discussed in the previous section. This can be confirmed by the coefficient of the mobile phones and regulatory quality in the CO₂ emissions, which have been found to be positive and negative, respectively in all the specifications.

⁴The Sargan and Hansen over-identification restrictions (OIR) tests should not be significant because their null hypotheses assumes that instruments are valid or not correlated with the error terms (Asongu and De Moor, 2017). In order to restrict identification (i.e. limit the proliferation of instruments), we have ensured that the number of instruments is lower than the number of cross-sections in most specifications.

In order to examine the threshold level at which inequality dampens the favourable negative effect of financial development on CO₂ emissions, the study computed threshold values for each income inequality proxy. The results show that the negative effect of financial development on CO₂ emissions can change to positive if the following inequality levels are exceeded: 0.591(332.803/562.909) for the Gini coefficient, 0.663(443.960/669.418) for the Atkinson index, and 5.454 (151.456/27.765) for the Palma ratio. Hence, policymakers should ensure that these inequality thresholds are not exceeded. This conception and definition of thresholds is of policy relevance and is consistent with a growing strand of policy-relevant literature, namely: conditions for patterns in investigated nexuses (Ashraf and Galor, 2013); turning points of CO₂ emissions that compromise inclusive development (Asongu, 2018b); critical levels of expected results (Batuo, 2015), and inequality levels at which the positive incidence of governance on gender economic participation is mitigated (Asongu and Odhiambo, 2020e). It is worth noting, however, that although the corresponding income inequality signs are negative, this negative effect should not be interpreted in isolation because it is due to the high correlation between the income inequality proxies and the interactive variable. For the computed thresholds to make economic sense and have policy relevance, they should be situated within the policy ranges of the variables presented in the summary statistics. This is vital because all the inequality critical points are within the minimum and maximum points indicated in the summary statistics.

Table 1: Financial Development (FD), Inequality and CO₂ emissions

Dependent variable: CO ₂ emissions (kt)						
	Gini Coefficient		Atkinson Index		Palma Ratio	
	Without conditioning information set	With conditioning information set	Without conditioning information set	With conditioning information set	Without conditioning information set	With conditioning information set
CO ₂ emissions (-1)	0.980*** (0.000)	0.998*** (0.000)	0.994*** (0.000)	1.003*** (0.000)	1.005*** (0.000)	1.014*** (0.000)
FD	-113.1821 (0.141)	-332.803** (0.019)	-336.262*** (0.000)	-443.960*** (0.000)	-164.284*** (0.000)	-151.456*** (0.000)
Gini Coefficient (Gini)	-21737.72*** (0.000)	-27441.8*** (0.000)	---	---	---	---
Atkinson Index (Atkinson)	---	---	-19878.52*** (0.000)	-28674.67*** (0.000)	---	---
Palma Ratio (Palma)	---	---	---	---	-1218.195*** (0.000)	-1291.339*** (0.000)
FD × Gini	166.806 (0.222)	562.909** (0.022)	---	---	---	---
FD × Atkinson	---	---	483.908*** (0.000)	669.418*** (0.000)	---	---
FD × Palma	---	---	---	---	26.660*** (0.000)	27.765*** (0.000)
Mobile Phones	---	18.665** (0.023)	---	24.631*** (0.003)	---	22.466*** (0.000)
Regulation Quality	---	-1490.961*** (0.020)	---	-3016.294*** (0.000)	---	-3124.826*** (0.000)
Positive Thresholds	NA(1)	0.591	0.694	0.663	NA(2)	5.454
Time Effects	Yes	Yes	Yes	Yes	Yes	Yes

AR(1)	(0.139)	(0.137)	(0.144)	(0.144)	(0.142)	(0.140)
AR(2)	(0.202)	(0.190)	(0.349)	(0.300)	(0.199)	(0.180)
Sargan OIR	(0.000)	(0.001)	(0.064)	(0.052)	(0.026)	(0.018)
Hansen OIR	(0.118)	(0.649)	(0.242)	(0.299)	(0.029)	(0.242)
DHT for instruments						
(a) Instruments in levels						
H excluding group	(0.093)	(0.427)	(0.038)	(0.210)	(0.085)	(0.137)
Dif(null, H=exogenous)	(0.188)	(0.650)	(0.534)	(0.386)	(0.049)	(0.383)
(b) IV (years, eq(diff))						
H excluding group	---	(0.444)	---	(0.099)	---	(0.108)
Dif(null, H=exogenous)	---	(0.668)	---	(0.639)	---	(0.510)
Fisher	243330.53***	62158.29***	125125.31***	62882.09***	237970.54***	112503.72***
Instruments	24	32	24	32	24	32
Countries	39	39	39	39	39	39
Observations	374	371	374	371	374	371

Note:

1) *** and ** denote significance levels at 1% and 5%, respectively.

2) DHT= Difference in Hansen Test for Exogeneity of Instruments Subsets.

3) Dif = Difference.

4) OIR = Over-identifying Restrictions Test.

5) NA (1) = Not applicable because both conditional and unconditional effects of financial development on CO₂ emissions are not significant in this specification.

6) NA (2) = Not applicable because the model is not valid.

7) The values in bold refer to: 1) The significance of estimated coefficients and the Fisher statistics. 2) The failure to reject the null hypotheses of: a) no autocorrelation in the AR(1) & AR(2) tests and; b) the validity of the instruments in the Sargan and Hansen OIR tests."

Conclusion

This paper examines the dynamic relationship between financial development, income inequality and CO₂ emissions in 39 sub-Saharan African (SSA) countries during the period 2004-2014. The study attempts to answer three critical questions: 1) Does financial development have any effect on CO₂ emissions? 2) Does the level of income inequality mitigate (affect) the impact of financial development on CO₂ emissions? 3) Is there a threshold level of income inequality that influences the impact of financial development on CO₂ emissions in SSA countries? Three income inequality indicators are used: the Gini coefficient, the Atkinson index and the Palma ratio. Financial development, on the other hand, is proxied by private domestic credit by deposit banks and other financial institutions. The study uses the General Methods of Moments (GMM) panel data analysis to examine these linkages. The study also uses interactive terms to examine the threshold level of income inequality at which the beneficial negative effect of financial development on CO₂ emissions becomes positive. The findings show that financial development unconditionally reduces CO₂ emissions (metric tons per capita) in the studied countries. This implies that increased financial deepening through financial development could reduce carbon emissions footprint in SSA countries. By efficiently allocating available funds to high yielding projects, an increase in financial development may enable domestic businesses to purchase environmentally-friendly technology, thereby reducing carbon emissions. The results further show that, although financial development leads to a reduction in CO₂ emissions in SSA countries, there is a threshold level of income inequality above which financial development tends to increase rather than reduce CO₂ emissions. Specifically, the study found that the negative effects of financial development on carbon emissions can change to positive if the following inequality levels are exceeded: 0.591 for the Gini coefficient, 0.663 for the Atkinson index and 5.454 for the Palma ratio. The study, therefore, recommends further development of the financial sector in the studied SSA countries in order to reduce carbon emissions and improve environmental quality. The study also recommends that policies designed to reduce high income inequality be implemented when the recommended income inequality threshold is exceeded, to enhance and sustain the negative impact of financial development on CO₂ emissions in SSA countries.

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Appendices

Appendix 1. Definitions of variables

Variables	Signs	Definitions of variables (Measurements)	Sources
Income Inequality	Gini Coefficient	The Gini coefficient is a measurement of the income distribution of a country's residents	GCIP
	Atkinson Index	The Atkinson index measures inequality by determining which end of the distribution contributed most to the observed inequality	GCIP
	Palma Ratio	The Palma ratio is defined as the ratio of the richest 10% of the population's share of gross national income divided by the poorest 40%'s share	GCIP
CO ₂ emissions	CO ₂	CO ₂ emissions (metric tons per capita)	WDI

Financial Development	FD	Private domestic credit from deposit banks and other financial institutions (% of GDP)	FDSD
Mobile Phones	Mobile	Mobile cellular subscriptions (per 100 people)	WDI
Regulation quality	RQ	measured as the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development	WGI

Note:

WDI: World Bank Development Indicators of the World Bank

FDSD: Financial Development and Structure Database of the World Bank

GCIP: Global Consumption and Income Project

WGI: World Governance Indicators of the World Bank.

Appendix 2. Summary statistics (2004-2014)

	Mean	SD	Minimum	Maximum	Observations
Gini Coefficient	0.586	0.034	0.488	0.851	428
Atkinson Index	0.704	0.057	0.509	0.834	428
Palma Ratio	6.454	1.477	3.015	14.434	428
CO ₂ emissions	18049.85	74847.66	73.34	503112.4	429
FD	21.055	25.319	0.873	150.209	414
Mobile Phones	47.148	37.672	1.272	171.375	425
Regulation quality	-0.601	0.544	-1.879	1.123	429

S.D: Standard Deviation.

Appendix 3. Correlation matrix (uniform sample: 409)

	CO2	Gini	Atkinson	Palma	FD	Mobile	RQ
CO ₂	1.000						
Gini	0.546	1.000					
Atkinson	0.235	0.789	1.000				
Palma	0.468	0.927	0.916	1.000			
FD	-0.085	-0.097	-0.184	-0.119	1.000		
Mobile	0.240	0.102	0.040	0.113	0.187	1.000	
RQ	0.309	0.281	0.105	0.273	0.326	0.442	1.000

Note:

CO₂: Carbon dioxide emissions.

Gini: the Gini Coefficient.

Atkinson: the Atkinson Index.

Palma: the Palma Ratio.

FD: Financial Development

Mobile: Mobile Phones Penetration.

RQ: Regulation Quality.